EXHIBIT 2

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existing data. The testing process needs to be continued until all feasible hypotheses have been tested and one is determined to be uniquely consistent with the facts and with the principles of science. If no hypothesis can withstand an examination by deductive reasoning, the issue should be considered undetermined.

4.3.6.1* Any hypothesis that is incapable of being tested either physically or analytically, is an invalid hypothesis. A hypothesis developed based on the absence of data is an example of a hypothesis that is incapable of being tested. The inability to refute a hypothesis does not mean that the hypothesis is true.

4.3.7 Select Final Hypothesis. The final step in applying the scientific method is to select the final hypothesis. Once the hypothesis has been tested, the investigator should review the entire process to ensure that all credible data are accounted for and all feasible alternate hypotheses have been considered and eliminated. When using the scientific method, the failure to consider alternate hypotheses is a serious error. A critical question to be answered is, "Are there any other hypotheses that are consistent with the data?" The investigator should document the facts that support the final hypothesis to the exclusion of all other reasonable hypotheses.

4.3.8 Avoid Presumption. No specific hypothesis can be reasonably formed or tested until some data have been collected. All investigations of fire and explosion incidents should be approached by the investigator without presumption as to origin, ignition sequence, cause, fire spread, or responsibility for the incident. All hypotheses should be subject to rigorous testing through the scientific method.

Δ **4.3.9 Expectation Bias.** Expectation bias is a phenomenon that occurs when investigator(s) reach a particular conclusion based on expectations without having examined or considered all of the relevant data. Instead of collecting and examining all of the data in a logical and unbiased manner, the investigator(s) uses the premature determination to influence analysis and investigative processes, including suggestive questioning of witnesses, which in turn might influence conclusions in a way that is not scientifically valid. The introduction of expectation bias into the investigation results in the use of only that data that supports this previously formed conclusion and often results in the misinterpretation or the discarding of data that does not support the original opinion. Investigators are strongly cautioned to avoid expectation bias through proper use of the scientific method.

Δ **4.3.10* Confirmation Bias.** Confirmation bias occurs when the investigator relies on data that supports the hypothesis and fails to look for, ignores, or dismisses contradictory or nonsupporting data. The same data may support alternate and even opposing hypotheses. The failure to consider alternate or opposing hypotheses, or prematurely discounting seemingly contradictory data without appropriate analysis and testing can result in incorrect conclusions. Testing a hypothesis is a process that considers all the data and alternative hypotheses to ascertain whether the tested hypothesis is inconsistent with data and, if inconsistent, whether an alternative hypothesis might also be true. When using the scientific method, testing of hypotheses should be designed to disprove a hypothesis (i.e., falsification of the hypothesis), rather than relying only on confirming data that support the hypothesis.

4.4 Basic Method of a Fire Investigation. Using the scientific method in most fire or explosion incidents should involve the steps shown in 4.4.1 through 4.4.6.

4.4.1 Receiving the Assignment. The investigator should be notified of the incident, told what his or her role will be, and told what he or she is to accomplish. For example, the investigator should know if he or she is expected to determine the origin, cause, and responsibility; produce a written or oral report; prepare for criminal or civil litigation; make suggestions for code enforcement, code promulgation, or changes; make suggestions to manufacturers, industry associations, or government agency action; or determine some other results.

4.4.2 Preparing for the Investigation. The investigator should marshal his or her forces and resources and plan the conduct of the investigation. Preplanning at this stage can greatly increase the efficiency and therefore the chances for success of the overall investigation. Estimating what tools, equipment, and personnel (both laborers and experts) will be needed can make the initial scene investigation, as well as subsequent investigative examinations and analyses, go more smoothly and be more productive.

4.4.3 Conducting the Investigation.

4.4.3.1 It is during this stage of the investigation that an examination of the incident fire or explosion scene is conducted. The fundamental purpose of conducting an examination of any incident scene is to collect all of the available data and document the incident scene. The investigator should conduct an examination of the scene if it is available and collect data necessary to the analysis.

4.4.3.2 The actual investigation may include different steps and procedures, which will be determined by the purpose of the assignment. These steps and procedures are described in detail elsewhere in the document. A fire or explosion investigation may include all or some of the following tasks: a scene inspection or review of previous scene documentation done by others; scene documentation through photography and diagramming; evidence recognition, documentation, and preservation; witness interviews; review and analysis of the investigations of others; and identification and collection of data from other appropriate sources.

4.4.3.3 In any incident scene investigation, it is necessary for at least one individual/organization to conduct an examination of the incident scene for the purpose of data collection and documentation. While it is preferable that all subsequent investigators have the opportunity to conduct an independent examination of the incident scene, in practice, not every scene is available at the time of the assignment. The use of previously collected data from a properly documented scene can be used successfully in an analysis of the incident to reach valid conclusions through the appropriate use of the scientific method. Thus, the reliance on previously collected data and scene documentation should not be inherently considered a limitation in the ability to successfully investigate the incident.

4.4.3.4 The goal of all investigators is to arrive at accurate determinations related to the origin, cause, fire spread, and responsibility for the incident. Improper scene documentation can impair the opportunity of other interested parties to obtain the same evidentiary value from the data. This potential impairment underscores the importance of performing comprehensive scene documentation and data collection.

how the procedures set forth in this chapter follow the scientific method.

18.5.1 Initial Hypothesis. The initial origin hypothesis is developed by considering witness observations, by conducting an initial scene assessment, and by attempting to explain the fire's movement through the structure. This process is accomplished using the methods described in earlier sections of this chapter. The initial hypothesis allows the investigator to organize and plan the remainder of the origin investigation. The development of the initial hypothesis is a critical point in the investigation. It is important at this stage that the investigator attempt to identify other feasible origins, and to keep all reasonable origin hypotheses under consideration until sufficient evidence is developed to justify discarding them.

18.5.2 Modifying the Initial Hypothesis. The investigation should not be planned solely to prove the initial hypothesis. It is important to maintain an open mind. The investigative effort may cause the initial hypothesis to change many times before the investigation is complete. The investigator should continue to reevaluate potential areas of origin by considering the additional data accumulated as the investigation progresses.

18.6 Testing an Origin Hypothesis for Validity. In order to conform to the scientific method, once a hypothesis is developed, the investigator must test it using deductive reasoning. A test using deductive reasoning is based on the premise that *if* the hypothesis is true, *then* the fire scene should exhibit certain characteristics, assuming that the fire did not subsequently obliterate those characteristics. For example, if a witness stated that a specific door was closed during the fire, then there should be a protected area on the door jamb, which would tend to prove the hypothesis that the door was closed. *(See Chapter 4 and A.4.3.6.)*

18.6.1 Means of Hypothesis Testing. During the investigation, the investigator may develop and test many hypotheses about the progress of the fire. For example, the investigator often has to determine whether a door or window was open or closed. Ultimately, the origin determination is arrived at through the testing of origin hypotheses. A technically valid origin determination is one that is uniquely consistent with the available data. In testing the hypothesis, the questions addressed in 18.6.1.1 through 18.6.1.3 should be answered.

18.6.1.1 Is there a competent ignition source at the hypothetical origin? The lack of a competent ignition source at the hypothesized origin should make the hypothesis subject to increased scrutiny. Investigators should be wary of the trap of circular logic. While the cause of the fire was at one time necessarily located at the point of origin, the investigator who eliminates a potential ignition source because it is "not in the area of the hypothesized origin," needs to be especially diligent in testing the origin hypothesis and in considering alternate hypotheses. *(See Section 19.2.)* This is particularly true in cases of full room involvement. Unless there is reliable evidence to narrow the origin to a particular portion of the room, every potential ignition source in the compartment of origin should be given consideration as a possible cause.

18.6.1.2 Can a fire starting at the hypothetical origin result in the observed damage? The investigator should be cautious about deciding on an origin just because a readily ignitible fuel and potential ignition source are present. The sequence of events that bring the ignition source and the fuel together and cause the observed damage indicates the origin, and ultimately the cause. The hypothetical origin should not only account for physical damage to the structure and contents, but also for the exposure of occupants to the fire environment.

18.6.1.3 Is the growth and development of a fire starting at the hypothetical origin consistent with available data at a specific point(s) in time? Few data are more damaging to an origin hypothesis than a contradictory observation by a credible eyewitness. Any data can be contradictory to the ultimate hypothesis. The data must be taken as a whole in considering the hypothesis, with each piece of data being analyzed for its reliability and value. Ultimately, the investigator should be able to explain how the growth and development of a fire, starting at the hypothesized origin, is consistent with the data.

18.6.2 Analytical Techniques and Tools. Analysis techniques and tools are available to test origin hypotheses. Using such tools and techniques to analyze the dynamics of the fire can provide an understanding of the fire that can enhance the technical basis for origin determinations. Such analyses can also identify gaps or inconsistencies in the data. The utility of fire dynamics tools is not limited to hypothesis testing. They may also be used for data analysis and hypothesis development. Techniques and tools include time line analysis, fire dynamics analysis, and experimentation.

18.6.2.1 Time Line Analysis. Time lines are an investigative tool that can show relationships between events and conditions associated with the fire. These events and conditions are generally time-dependent, and thus, the sequence of events can be used for testing origin hypotheses. Relevant events and conditions include ignition of additional fuel packages, changes in ventilation, activation of heat and smoke detectors, flashover, window breakage, and fire spread to adjacent compartments. Much of this information will come from witnesses. Fire dynamics analytical tools *(see 21.4.8)* can be used to estimate time-dependent events and fire conditions. A more detailed discussion of time lines is included in Section 21.2.

18.6.2.2 Fire Modeling. Fundamentals of fire dynamics can be used to test hypotheses regarding fire origin. Such fundamentals are described in the available scientific literature and are incorporated into fire models ranging from simple algebraic equations to more complex computer fire models *(see 21.4.8)*. The models use incident-specific data to predict the fire environment given a proposed hypothesis. The results can be compared to physical and eyewitness evidence to test the origin hypothesis. Models can address issues related to fire development, spread, and occupant exposure.

18.6.2.3 Experimental Testing. Experimental testing can be conducted to test origin hypotheses. If the experimental testing results are substantially similar to the damage at the scene, the experimental data can be said to be consistent with the origin hypothesis. If the experimental testing produces results that are not substantially similar with the damage, an alternative origin hypothesis or additional data may need to be considered, taking into account potential differences between the experimental testing and the actual fire conditions. The following is an example of such an experiment. The hypothesized origin is a wicker basket located in the corner of a wood-paneled room. The data from the actual fire shows the partial remains of the wicker basket, undamaged carpet in the corner, and wood paneling still intact in the corner. A fire test replicating the hypothesized origin totally consumes the carpet, the wicker basket, and the wood paneling. Thus (assuming the test replicated the prefire conditions), testing revealed that this

(3) Ignition of secondary fuel items
(4) Thermal transmission through building elements

21.4.3 Flammable Gas Concentrations. Models can be used to calculate gas concentrations as a function of time and elevation in the space and can assist in identifying ignition sources. Flammable gas concentration modeling, combined with an evaluation of explosion or fire damage and the location of possible ignition sources, can be used (a) to establish whether or not a suspected or alleged leak could have been the cause of an explosion or fire, and (b) to determine what source(s) of gas or fuel vapor were consistent with the explosion or fire scenario, damage, and possible ignition sources.

21.4.4 Hydraulic Analysis.

21.4.4.1 Analysis of automatic sprinkler and water supply systems is often required in the evaluation of the cause of loss. The same mathematical models and computer codes used to design these systems can be used in loss analysis. However, the methods of application are different for design than they are for forensic analysis.

21.4.4.2 A common application of hydraulic analysis is to determine why a sprinkler system did not control a fire. Modeling can also be used to investigate the loss associated with a single sprinkler head opening, to investigate the effect of fouling in the piping, and to determine the effect of valve position on system performance at the time of loss. There are also models and methods available to analyze flow through systems other than water-based systems, such as carbon dioxide, gaseous suppression agents, dry chemicals, and fuels.

21.4.5 Thermodynamic Chemical Equilibrium Analysis. Fires and explosions believed to be caused by reactions of known or suspected chemical mixtures can be investigated by a thermodynamics analysis of the probable chemical mixtures and potential contaminants.

21.4.5.1 Thermodynamic chemical equilibrium analysis can be used to evaluate various hypotheses, including those relating to the following:

(1) Reaction(s) that could have caused the fire/explosion
(2) Improper mixture of chemicals
(3) Role of contamination
(4) Role of ambient conditions
(5) Potential of a chemical or chemical mixture to overheat
(6) Potential for a chemical or chemical mixture to produce flammable vapors or gases
(7) Role of human action on process failures

21.4.5.2 Thermodynamic reaction equilibrium analysis traditionally required tedious hand calculations. Currently available computer programs make this analysis much easier to perform. The computer programs typically require several material properties as inputs, including chemical formula, mass, density, entropy, and heat of formation.

21.4.5.3 Chemical reactions that are shown not to be favored by thermodynamics can be eliminated from consideration as the cause of a fire. Thermodynamically favored reactions must be further analyzed to determine whether the kinetic rate of the considered reactions is fast enough to have caused ignition, given the particular circumstances of the fire.

21.4.6 Structural Analysis. Structural analysis techniques can be utilized to determine reasons for structural failure or change during a fire or explosion. Numerous references can be found in engineering libraries, addressing matters such as strength of materials, formulas for simple structural elements, and structural analysis of assemblies.

21.4.7* Egress Analysis. The failure of occupants to escape may be one of the critical issues that an investigator needs to address. Egress models can be utilized to analyze movement of occupants under fire conditions. Integrating egress models with a fire dynamics model is often necessary to evaluate the effect of the fire environment on the occupants. See Section 11.3 on human factors.

21.4.8* Fire Dynamics Analysis. Fire dynamics analyses consist of mathematical equations derived from fundamental scientific principles or from empirical data. They range from simple algebraic equations to computer models incorporating many individual fire dynamics equations. Fire dynamics analysis can be used to predict fire phenomena and characteristics of the environment such as the following:

(1) Time to flashover
(2) Gas temperatures
(3) Gas concentrations (oxygen, carbon monoxide, carbon dioxide, and others)
(4) Smoke concentrations
(5) Flow rates of smoke, gases, and unburned fuel
(6) Temperatures of the walls, ceiling, and floor
(7) Time of activation of smoke detectors, heat detectors, and sprinklers
(8) Effects of opening or closing doors, breakage of windows, or other physical events

21.4.8.1 Fire dynamics analyses can be used to evaluate hypotheses regarding fire origin and fire development. The analyses use building data and fire dynamics principles and data to predict the environment created by the fire under a proposed hypothesis. The results can be compared to physical and eyewitness evidence to support or refute the hypothesis.

21.4.8.2 Building, contents, and fire dynamics data are subject to uncertainties. The effects of these uncertainties should be assessed through a sensitivity analysis and should be incorporated in hypothesis testing. Uncertainties may include the condition of openings (open or closed), the fire load characteristics, HVAC flow rates, and the heat release rate of the fuel packages. See Section 21.6 for recommended data-collection procedures.

21.4.8.3 Fire dynamics analyses can generally be classified into three categories: specialized fire dynamic analyses, zone models, and field models. They are listed in order of increasing complexity and required computational power.

21.4.8.3.1* Specialized Fire Dynamics Routines. Specialized fire dynamics routines are simplified procedures designed to solve a single, narrowly focused question. In many cases, these routines can answer questions related to a fire reconstruction without the use of a fire model. Much less data is typically required for these routines than is required to run a fire model. Examples of fire dynamics routines can be found in NUREG–1805, Fire Dynamics Tools (FDTs).

21.4.8.3.2 Zone Models. Most of the fire growth models that can be run on personal computers are zone models. Zone models usually divide each room into two spaces or zones, an upper zone that contains the hot gases produced by the fire, and a lower zone that is the source of the air for combustion. Zone sizes change during the course of the fire. The upper zone can expand to occupy virtually all the space in the room.

21.4.8.3.3 Field, Computational Fluid Dynamics (CFD) Models. CFD models usually require large-capacity computer work stations or mainframe computers. By dividing the space into many small cells (frequently tens of thousands), CFD models can examine gas flows in much greater detail than zone models. Where such detail is needed, it is often necessary to use the sophistication of a field model. In general, however, field models are much more expensive to use, require more time to set up and run, and often require a high level of expertise to make the decisions required in setting up the problem and interpreting the output produced by the model. The use of CFD models in fire investigation and related litigation, however, is increasing. CFD models are particularly well suited to situations where the space or fuel configuration is irregular, where turbulence is a critical element, or where very fine detail is sought.

21.4.9 Guidelines for Selection and Use of a Fire Model. Fire dynamics analyses, particularly those that use fire models, can evaluate hypotheses regarding fire origin and fire development. The methodology for selecting and using a fire model is presented in the SFPE *Engineering Guide: Guidelines for Substantiating a Fire Model for a Given Application* and graphically depicted in Figure 21.4.9.

21.4.9.1 Defining the Problem. The investigator/analyst needs to be able to articulate the question for which modeling is sought. The investigator should state why the problem warrants a numerical study and what fire dynamics assessments of the problem have been previously conducted of this incident. The key fire phenomena and physics should be described (e.g., heat transfer, combustion, and materials response) along with their understanding of how they apply to the problem. The selection process includes determining if a model is applicable to the question and, if applicable, choosing an appropriate model to generate output adequate to answer the question posed.

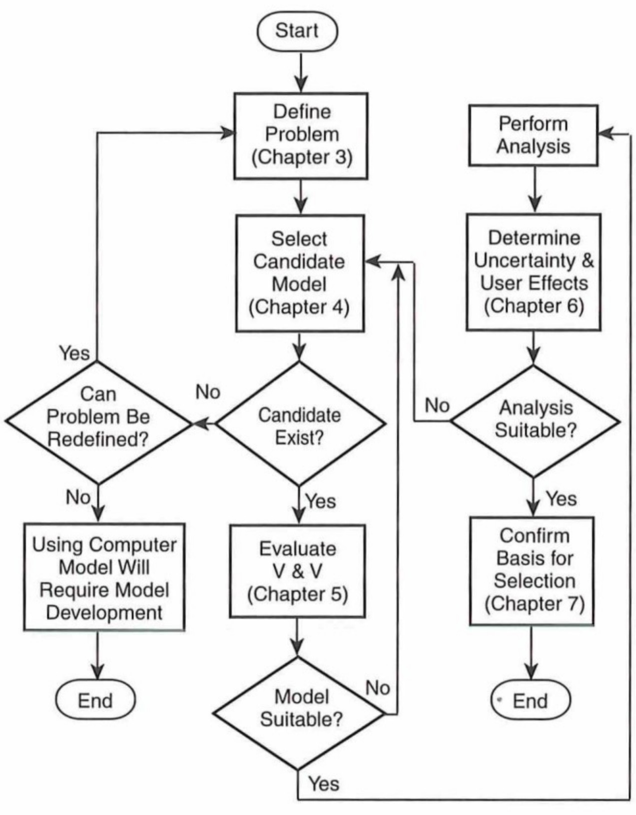

FIGURE 21.4.9 Fire Model Selection Flowchart.

21.4.9.2 Select a Candidate Model. There is a selection of fire models used for predicting fire phenomena. In addition to the required output, selection factors include computational resources, time limitations, level of accuracy, available input data, and underlying governing equations. The modeler should consider the range of candidate models and may use multiple models for comparison purposes. If no candidate model exists, the problem may require redefinition or a new model may need to be developed. The analyst should evaluate the available information for input to the model, the desired outputs, and the resources available.

21.4.9.3 Model Verification and Validation. The SFPE *Engineering Guide: Guidelines for Substantiating a Fire Model for a Given Application* emphasizes that before selecting a model for a particular problem, the analyst needs to determine if the selected model is capable of generating a useful result. This process, known as verification and validation (V & V), is set forth in ASTM E1355, *Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models.* Model developers should have already performed this process, and their V & V data should be available in the documentation. The US Nuclear Regulatory Commission (NRC) has conducted V & V studies that may be useful. See Figure 21.4.9.3(a) and Figure 21.4.9.3(b) for a comparison of predicted versus measured values.

21.4.9.4 Uncertainty and User Effects. As with any mathematical or computational model, the magnitude or uncertainty of the results relies not only on the model but the choices made for data input and interpretation of the results. This uncertainty is referred to as user effects and must be taken into consideration. User effects can be addressed by conducting evaluations, such as sensitivity analyses or comparison to other model results.

21.4.9.5 Documentation. The documentation of the entire process is important to any case. This documentation should include the following:

(1) Defining of the problem and key physics and fire phenomena
(2) Selection of the candidate model or models and their inputs and outputs
(3) Applicable V & V referenced citations
(4) Evaluation of user effects
(5) The data files used with the selected model or models

21.5 Fire Testing.

21.5.1 Role of Fire Testing. Fire testing is a tool that can provide data that complement data collected at the fire scene *(see 4.3.3)*, or can be used to test hypotheses *(see 4.3.6)*. Such fire testing can range in scope from bench scale testing to full-scale recreations of the entire event. These tests may relate to the origin and cause of the fire, or to fire spread and development. The components and subsystems to be tested may include building contents, building systems, and architectural and structural elements of the building itself.